An Energy Account for Spaceship Earth

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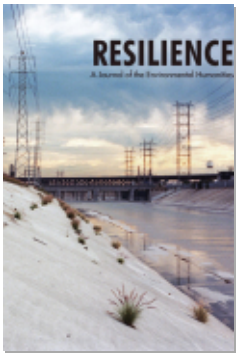

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Abstract: This article positions the inventor, visionary, poet, engineer, architect, and scientist R. Buckminster Fuller as an epic storyteller about energy (although he might have preferred the tag "comprehensive anticipatory design scientist"). It draws on energy accounts from a range of Fuller's lectures, workshops, and books, from his *Operating Manual for Spaceship Earth* to his recommendations for the creation of a "global energy grid." It discusses Fuller's energy perspectives, and those related to his, from the 1940s through the twenty-first century. Fuller's ideas of synergetics and a scenario universe incorporating a "world-around" energy grid have continued to inspire current energy road maps. His energy storytelling was the infrastructure for a "world accounting system based on energy." The challenges of energy resources, energy security, and energy transition persist today, albeit in revised forms. Current talk of circular economies, planetary boundaries, and system transformations is usually presented without acknowledgement, or perhaps awareness, of the rich and imaginative visual and textual storytelling that have served as their foundations. The article revisits Fuller's energy narratives and asks what kinds of storytelling are possible and productive when thinking about energy in the Anthropocene.

Keywords: Spaceship Earth, energy systems, geoengineering, planetary boundaries, Anthropocene

Introduction

> I must observe also that we're not going to sustain life at all except by our successful impoundment of more of the Sun's radiant energy aboard our spaceship than we are losing from Earth in the energies of radiation or outwardly rocketed physical matter. We could burn up the Spaceship Earth itself to provide energy, but that would give us very little future.
>
> —R. Buckminster Fuller, *Operating Manual for Spaceship Earth*

R. Buckminster Fuller's story of humanity's future aboard Spaceship Earth was also a story about energy. Fuller was an inventor, visionary, poet, engineer, sailor, architect, and scientist, and he was one of the best-known public intellectuals of the 1960s. In 1964 the very first BBC *Horizon* program was a profile: "The World of Buckminster Fuller." Fuller's world provided Stewart Brand with inspiration for the *Whole Earth Catalog*,[1] while John Cage, writing in 1971, predicted that the twenty-first century would regard the revolutionary era of the 1960s as one defined by Fuller.[2] Fuller was famous for giving impromptu and comprehensive lectures about industrial design problems and environmental crises, weaving together life experiences with complex scientific theories. His varied publications on humanity's perceived predicament attempted to cover an astonishingly broad scope. His unruly theoretical excursions were littered with neologisms and unorthodox punctuation. Above all, Fuller was a storyteller concerned with the future. Fuller, the self-styled "prognosticator" and "forecaster,"[3] should perhaps most appropriately be termed a "comprehensive anticipatory design scientist" in recognition of his redefinition of design thinking.[4] Fuller often referred to the function of a "trim tab"—a miniature rudder—in nautical design as a metaphor for how individuals could make a difference in the world and change the course of humanity. With its image of subtle action provoking a substantial shift, the trim tab, according to Fuller, "demonstrates the principle of self-regenerative amplification, on which the original cybernetic experience is based and from which the feedback control system is derived, namely how one navigates a ship."[5] "Call me Trim-Tab" was Fuller's imperative, echoing another mariner of a distinctly internationalist-idealist bent.[6]

Fuller's ideas—suffused with industrial dynamics, cybernetics, cartographic consciousness, and nautical perspectives—were demonstrated in what he called "artifacts," prototypes or realizations of his designs and concepts. He is perhaps best known for his work on geodesic domes, inspired by the processes, systems, and structural integrities found in nature. Among these was the Dome over Manhattan project of 1960 with Shoji Sadao, which proposed to encapsulate a two-mile-diameter section of the city in the event of "environmental and other emergencies." At once implicated in the history of climate modification and geoengineering, such projects also revealed his penchant for planet shaping. Fuller is credited with popularizing

the idea of ephemeralization, or "the doing of ever more with ever less, per given resource units of pounds, time, and living in ever-increasing numbers."[7] For Fuller this transpired as a counterforce to "the entropic energy losses to Universe occasioned by our emergency-urged fortuitous exploitation of spaceship Earth's inventory."[8] The ephemeralization principle is at the core of contemporary cradle-to-cradle thinking, environmental efficiency, and sustainability paradigms.[9] While rarely acknowledged by environmentalists, Fuller is credited with anticipating much contemporary environmental thought and practice in the twentieth century.[10]

Most significantly, Fuller contributed to establishing the notion of Spaceship Earth—the audacious redefinition of the home planet as a vehicle journeying in space. In 1969 Fuller published his *Operating Manual for Spaceship Earth*, where he described Earth as "an integrally-designed machine which to be persistently successful must be comprehended and serviced in total."[11]

The title of this article, "An Energy Account for Spaceship Earth," refers to the multiple meanings of the word *account*: narrative, chronicle, record, story, as well as measure, justification, calculation, tally, or inventory. Energy accounts can take many forms, including depictions of data, visualizations of resource flows, and narratives of energy use. Spaceship Earth, a framing of the planet in technoscientific terms as a hybrid entity, was a figure adopted by both environmentalists and technocrats to argue very different positions in the same terms.[12] It called up notions of earthly lifeboat, earth ark, earth system, or earthly replica. Fuller's mode of narration about Spaceship Earth and its entanglements encapsulates the tendency to attempt to bring technology, society, and environment to a single horizon of understanding. It displays the simultaneity of energetic storytelling and accounting procedures. It both captures and provokes a condition whereby the storyteller covers for the engineer or the prophet saves the day for the bookkeeper.

Spaceship Earth was a prominent concept from the 1960s to the 1990s, when it was gradually replaced with the concept of sustainability. It nevertheless continued as a reference point in thinking about environmental sustenance, technical maintenance, and planetary governance. It has resurged more recently in anthropogenic climate change deliberations and in particular in the twenty-first-century discourse of the Anthropocene and "planetary boundaries."[13] These all

reference the perceived threat of earthly limits and a doomed future for planet Earth and its inhabitants through their own activities—that is, through the uses and abuses of energy. Discussions around energy transitions away from a fossil fuel economy, the intense depletion of resources, and questions about future energy systems have sparked renewed interest in questions of planetary management and stewardship, albeit with a technical managerial tenor.[14] Arguments over a "good or bad Anthropocene" are also anticipated in Fuller's storytelling,[15] which presented humanity as a planet-changing force headed toward, in his words, "utopia or oblivion."[16] The Anthropocene is a "planetary conjuncture" where the geologic past, the environmental present, and energetic futures collide.[17] At the same time, the Anthropocene and its "unconformities" reproduce the conditions of what has been called the "impasse" in energy humanities.[18] Imre Szeman has suggested, "We know where we stand with respect to energy, but we do nothing about it."[19] The Anthropocene, like the story of Spaceship Earth before it, is in itself a particular form of energy account—"a cautionary tale of its own making. It is a fearsome story told to try to make sense of the calamity-ridden world we find ourselves in."[20]

Spaceship Earth

In the 1960s the space missions represented the epitome of what modern technological society could accomplish. At the same time, they called attention to environmental concerns about the planet: overpopulation, pollution, and exhaustion of resources. The most familiar images of humanity's home planet are the NASA photographs *Earthrise* (taken from *Apollo 8* on December 24, 1968) and the *Blue Marble*, or *Whole Earth* (taken from *Apollo 17* on December 7, 1972). The astronauts' view of Earth from space was also famously invoked in the Brundtland report, *Our Common Future*, in 1987. These images, associated with both the space age and the environmental movement, introduced the twin ideologies of "one world" (i.e., human universality) and the "whole earth" (i.e., fragile ecology). In *Apollo's Eye* Cosgrove argues that, although superficially contradictory, both global visions—the "world without borders" and the "delicate bounded earth"—were tied to a "global mission" of "human territoriality."[21] Apollo's eye is "synoptic and omniscient, intellectually detached."[22] At the same time, these

technologically produced images created an illusion of "whole earth" as an artifact, "which could be managed and encoded into systems or geo-engineered."[23] In other words, the world could be understood as Spaceship Earth. The Apollo missions had permitted the astronauts in a tiny artificial capsule to capture a view of Earth from space. In turn, this allowed for Earth itself to be conceived of as a spaceship, constantly worried about, monitored, and controlled.

We see something of R. Buckminster Fuller's particular notion of Spaceship Earth and its energy account in *Nine Chains to the Moon*, his stargazing narrative from 1938. Before visits to space were considered possible, Fuller was calling for more adventurous thinking so that "earthians" could achieve their full cosmic potential. He writes,

> Scientific shelter design is linked to the stars far more directly than to the earth. STAR-GAZING? Admittedly. But it is essential to accentuate the real source of energy and change in contrast to the emphasis that has always been placed on keeping man "down to earth". The teleologic dwelling designer MUST visualize his little shelters upon the minutely thin dust surface of the earth-ball, dust which is a composite of inert rock erosion, star dust, and vegetable compost, all direct star (sun) energy resultants.[24]

Fuller's dusty "earth-ball" was intimately connected to the stars—its source of cosmic energy and change. When the era of space travel ushered in Earth observation—an "inverted astronomy"[25]—it provoked increasing awareness of the planet as a life-support system. At the same time, technical know-how was focused on the problem of the physical vulnerability of passengers in tiny space capsules. It was inevitable that the idea of the spaceship as a surrogate Earth would emerge. In the 1960s the concept of the cyborg—or cybernetic organism, a hybrid of the organic body and machine technology—was promoted in advancing adaptations to astronautics.[26] The cyborg was understood as being "moved by the energy of atoms or particles, and controlled by a circuit of communications."[27] Spaceship Earth as cyborg, or human-machine hybrid, indicates also Donna Haraway's fractured identities of organisms and machines and the blurring of boundaries between social realities and science fictions.[28]

The idea of Earth as a spaceship, a closed system with finite resourc-

es, was allegedly first used by Fuller in a discussion about the US space rocket program in 1951 and later in lectures in the 1960s at MIT, Harvard University, Black Mountain College, and other academic venues.[29] In the context of midcentury anxieties—above all, relating to the Cold War—there was enormous appeal in the notion of planet Earth as a unified, balanced, and steerable artifact. Taking stock of energy scarcity and entropic breakdown in his 1950 publication on cybernetics, Norbert Weiner declared that humans were "shipwrecked passengers on a doomed planet."[30] The only apparent escape route from the perceived energy crisis was to develop hybrid human-technological regimes capable of reshaping a planetary society. Throughout his various texts, Fuller consistently warned of the dangers threatening humankind, including poverty, economic inequality, pollution, energy consumption, and warring nations. But he also offered a supremely optimistic account of humanity's purpose and potential. In 1969 Fuller published his version of Earth stewardship, informed by systems theory and cybernetics: *Operating Manual for Spaceship Earth: A Bold Blueprint for Survival That Diagnoses the Causes of Environmental Crisis*. In Fuller's terms the new conditions for humanity required acknowledging that "we are all astronauts."[31]

Fuller's book took part in the redefinition of Earth as a spaceship—artifact, vehicle, and system. Fuller's spaceship had a limited carrying capacity, merging scant resources with spatial constraints in a vision of Earth as a fragile craft.[32] If Earth was comprehended as a spaceship (i.e., an "integrally-designed machine"),[33] then it followed that the crew needed to exercise care and concern for maintaining the livable conditions on board—or as space scientists would describe them, the life-support systems, which mimic on space stations the constraints of Earth's biosphere. Steering the earth craft involved management of atmosphere; water; resources; and, above all, energy. Fuller cautioned that "up to now we have been mis-using, abusing and polluting this extraordinary chemical energy–interchanging system for successfully regenerating all life aboard our planetary spaceship."[34] According to Fuller, the most important condition for the passengers aboard Spaceship Earth was that they had not been provided with an instruction manual. Humans had inhabited Earth for approximately 2 million years "hardly knowing they were onboard a ship." The implication was that Spaceship Earth—a dy-

namic, mobile, designed, hypersensitive object at risk of malfunction—was no longer as tolerant of human ignorance: "We have thus discovered also that we can make all of humanity successful through science's world engulfing industrial evolution provided that we are not so foolish as to continue to exhaust in a split second of astronomical history the orderly energy savings of billions of years' energy conservation aboard our Spaceship Earth."[35] Fossil fuels—accumulated over billions of years—were Spaceship Earth's "savings account" or "storage battery." They were described by Fuller as being deposited through the action of dynamic earth processes: "photosynthesis and progressive, complex, topsoil fossilization buried ever deeper within Earth's crust by frost, wind, flood, volcanoes, and earthquake upheavals."[36] Fuller's depiction of readily available cosmic energy reads like a paean to renewable energy; only by understanding Earth's scheme could humanity continue to "progressively harness evermore of the celestially generated tidal and storm generated wind, water, and electrical power concentrations."[37] In many ways, Fuller anticipated twenty-first-century attempts to recast Earth's energy system in terms of zero-carbon energy accounting: "The natural energy income in, for instance, the harnessable ocean tides, wind sunpower and alcohol-producing vegetation, can be made to flow through the wires and pipes to bring adequate energy to bear on the levers, to step-up man's physical vantage efficiently to take care of all of humanity."[38] By taking account of Spaceship Earth's cosmic inventory, Fuller was advocating a radical transition in energy use that was simultaneously a civilizational paradigm shift of benefit to all humanity. Fuller's energy account for Spaceship Earth came with a warning: "We cannot afford to expend our fossil fuels faster than we are 'recharging our battery,' which means precisely the rate at which the fossil fuels are being continually deposited within Earth's spherical crust."[39] Keeping Spaceship Earth with a fully charged battery on a steady course would be the responsibility of "planners, architects and engineers," as, according to Fuller, these professions and practices allowed for a more holistic rather than specialized view and were thus considered more capable in taking on the managerial responsibilities for Spaceship Earth. They would be aided by the principles of good management and the use of a state-of-the-art computer monitoring of Earth. The computer, Fuller argued, was capable of "bringing all of humanity in for a happy landing."[40]

Earth Stewardship

The successful piloting of Spaceship Earth was linked to notions of earth governance and control expressed as stewardship. The economist Kenneth Boulding took up the metaphor of the well-organized spacefaring machine in his 1966 article "The Economics of the Coming Spaceship Earth."[41] Boulding argued that in terms of open or closed systems, "three important classes are matter, energy, and information. The present world economy is open in regard to all three." However, for the necessarily "closed Earth of the future," he proposed a "spaceman economy" or "closed economic system" with an ethic of responsible management of Earth as opposed to the "cowboy economy" of the "open system":

> For the sake of picturesqueness, I am tempted to call the open economy the "cowboy economy", the cowboy being symbolic of the illimitable plains and also associated with reckless, exploitative, romantic, and violent behavior, which is characteristic of open societies. The closed economy of the future might similarly be called the "spaceman" economy, in which the earth has become a single spaceship, without unlimited reservoirs of anything, either for extraction or pollution, and in which, therefore, man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy.[42]

Spaceship Earth offered the blueprint for a strict economy of circulation and for a technology of energy and information flows, of material exchange and renewal, for Earth's living space. Intimations of the frontier thesis of American history and cultural politics are self-evident. In the spaceship economy, informed by notions of scarcity, the primary concern was tight control of reserves, or "stock maintenance." Boulding argued for the need to change the view of the world, from a limitless frontier to a Spaceship Earth. His perspective was influential in the development of ecological economics, the notion of an ecological footprint, and living within planetary limits.

In 1966 the British economist and political scientist Barbara Ward published *Spaceship Earth*, which promoted a science-based politics that could redirect social energy. "This space voyage is totally precarious," she wrote. "We depend upon a little envelope of soil and a rather

larger envelope of atmosphere for life itself. And both can be contaminated and destroyed."[43] As Sabine Höhler observes, "the spaceship became an allegory for the need of a new balance of power between the continents, of wealth between North and South, and of understanding and tolerance in a world of economic interdependence and potential nuclear destruction."[44] In Ward's words, "In the last few decades, mankind has been overcome by the most fateful change in its entire history. Modern science and technology have created so close a network of communication, transport, economic interdependence—and potential nuclear destruction—that planet earth, on its journey through infinity, has acquired the intimacy, the fellowship, and the vulnerability of a spaceship."[45] For Ward, the United Nations held the promise of expertly steering the unity of the planet's carrying capacity.[46] Her later writings were coauthored with French environmentalist René Dubos, including a publication produced to coincide with the UN Stockholm Conference on the Environment in 1972—the first Earth Summit. The publication—titled *Only One Earth: The Care and Maintenance of a Small Planet*—was presented, like Fuller's book, as a technical reference manual, with its call for humanity to "accept responsibility for stewardship of the earth." The vision of Earth as a single, integrated system—the Apollo's-eye view—merged with the one-boat motif of the 1972 UN publication to arrive at the conviction that all of humanity is confined to a common vessel and share a common fate—sink or swim—within absolute limits.[47]

Concerns around resource security and environmental security supplemented the global issues of military and energy security at a time when the environment was understood to be more under the control of humans than ever before, not least because the human potential for technological intervention was so unprecedented. In the 1960s, Spaceship Earth became a rallying call for the environmental movement. It offered not only a way of expressing humanity's common interest in understanding the global environment as a system of sustenance but also a way of signaling its predicament. But the metaphor of Spaceship Earth was troubling; it offered little room for deviating from a preordained course. As Oliver Morton observes, "the metaphor of the spaceship plays up holism and hides the contingency of the earth system. It implies that there is a single ship-shape way that the Earth should run. It encourages the notion that there is a fixed limit to the Earth's carrying capacity, just as there is a fixed complement

for a vessel—an argument that has been used to justify brutal ideas about population control. And it can be used to divide humans into officers, crew and supercargo."[48] Among those who promoted the idea of Spaceship Earth as an "overloaded lifeboat" in the 1970s were Paul Ehrlich and Garrett Hardin, but the argument has also resurfaced more recently—for example, in the writings of James Lovelock on "Lifeboat UK."[49] Garrett Hardin's 1972 science fiction parable *Exploring New Ethics for Survival: The Voyage of the Spaceship Beagle* interweaves an exposition of the "population problem,"[50] within the framework of a story set aboard a spaceship named *Beagle*, a space-age counterpart of Darwin's famous vessel.[51] Hardin wrote this tale as an extension of his contested 1968 essay, "The Tragedy of the Commons."[52] Hardin used talk of a troubled Spaceship Earth to advocate the suspension of humanistic moral values in favor of "lifeboat ethics"—derived from naval law and practice. The scientific systems of the spaceship could provide energy, synthesis of food, and recycling of waste. In other words, it had proven technology capable of supplying all "daily needs." It was impossible, however, to expect any kind of stability from the changeable, argumentative, and fickle passengers—in other words, "the real problem of a spaceship is its people."[53]

Earth systems sciences have developed in tandem with military-industrial research on capsule living in submarines, nuclear shelters, and spaceships; and through the Spaceship Earth metaphor, earth systems sciences have presented Earth as a graspable, monitorable, and manageable entity. The imaginary of the sealed cabin of the spacecraft, a compact shelter in a vast and hostile environment, also evoked (at least for American thinkers) the self-reliant homesteading of the frontier—an analogy that should have troubled some Spaceship Earth thinkers more than it appears to have done. If the home planet was bounded and full to capacity, then it could also be imagined as a lifeboat or forward base for resettlement projects and space cities in a boundless universe. The idea of Spaceship Earth found its literal embodiment in Biosphere 2—an earth systems research facility built in the Arizona desert between 1987 and 1991 intended as both a proxy space settlement and analogue for Earth.[54] Spaceship Earth thinking thus helped to establish the planet as a temporary biospheric environment (i.e., "Biosphere 1") and opened up the prospect of leaving Earth—and its troubles—behind altogether.[55]

The notion of a well-managed system, the idea of a steady state econ-

omy, political unity, good governance, and effective control as principles of earth stewardship were all implied in Fuller's energy account for Spaceship Earth. However, his vision contrasted sharply with the Malthusian or even anthropophobic tendencies of Hardin and Ehrlich. In the context of perceived energy crises, Fuller had stated, "There is no energy shortage. There is no energy crisis. There is a crisis of ignorance."[56] Fuller held up human ingenuity against all possible limits with regard to the planet's cosmic energy. He argued that while growing populations might consume more, this would not exhaust the world's natural resources because of exponential advances in ephemeralization—doing more with less. In a typically energetic pronouncement, Fuller insisted that in terms of world population, resource distribution was more of an issue than sheer numbers: "There is room enough indoors in New York City for the whole 1963 world's population to enter, with room enough inside for all hands to dance the twist in average nightclub proximity."[57]

Global Energy Grid

For Fuller the term *energetic* encompassed his conception of the universe as an enormous field of energy with our planet acting as a "spinning, cosmos-zooming earth ball." His neologism "synergetic" combined *energetic* with *synergy* to refer to the integration of energy in a system. Earthians, he surmised, were more than capable not only of realizing their cosmic-energy potential but also of living within their energy means. It was their fossil-fueled success that had gotten them into trouble:

> We are in an unprecedented crisis because cosmic evolution is also irrevocably intent upon making omni-integrated humanity omni-successful, able to live sustainingly at an unprecedentedly higher standard of living for all Earthians than has ever been experienced by any; able to live entirely within its cosmic-energy income instead of spending its cosmic energy savings account (i.e., the fossil fuels) or spending its cosmic-capital plant and equipment account (i.e., atomic energy)—the atoms with which our Spaceship Earth and its biosphere are structured and equipped—a spending folly

> no less illogical than burning your house-and-home to keep the family warm on an unprecedentedly cold midwinter night.[58]

This trenchant quote from *Critical Path* summarizes Fuller's view of the global crisis as one of reckless and illogical energy expenditure on Spaceship Earth. According to him, the first task on humanity's "critical path" to averting the crisis would be to build a global energy grid to stop needless squandering of the "cosmic energy savings account." Fuller's research led him to conclude that humanity could satisfy 100 percent of its energy needs while phasing out fossil fuels and nuclear power. In one example, he calculated that a wind turbine fitted to every high-voltage transmission tower in the United States could generate three and a half times the country's total power output at the time. Fuller predicted that his global energy grid would be operational by 1989: "The world energy network grid will be responsible for the swift disappearance of planet Earth's 150 different nationalities. We now have 150 supreme admirals, all trying to command the same ship to go in different directions, with the result that the ship is going around in circles—getting nowhere."[59] Fuller's Global Energy Network International (GENI) would make the most efficient use of the energy-generating capacity in different parts of the world, sending surplus to satisfy demands wherever needed. It was seen as a way of distributing renewable energy around the planet and dealing with the intermittency and availability problems suffered by solar and wind power in particular. Fuller developed his ideas for a scenario universe incorporating this "world-around" energy grid. He tested his claims that the energy grid had world-unifying potential in the World Game, conceived as an antidote to Cold War military games and doomsday scenario planning but nevertheless drawing on the same techniques. Fuller called for the elimination of nations in favor of a single government that would operate in the interests of the entire planet, making it work for all humanity. The World Game was intended to be a methodology as well as a program for world improvement. The giant simulation explicitly declared energy as the basis for society. The political-social-resource scenario game relied on a computer to gather data and make allocations of resources based on need. It required serious game playing for a logical reorganization of all of the world's resources and proposed no less than an end to the Cold War and the institution of world peace:

> To the World Game seminar of 1969 I presented my integrated, world-around, high-voltage electrical energy network concept. Employing the new 1500-mile transmission reach, this network made it technically feasible to span the Bering Straits to integrate the Alaskan U.S.A. and Canadian networks with Russia's grid, which had recently been extended eastward into northern Siberia and Kamchatka to harness with hydroelectric dams the several powerful northwardly flowing rivers of north-easternmost U.S.S.R. This proposed network would interlink the daylight half of the world with the nighttime half.[60]

The World Game was played on versions of Fuller's Dymaxion Sky–Ocean World Map (1943)—a new cartographic logic for mapping Earth as an undistorted projection of contiguous islands surrounded by ocean, indeed the world as seen by a circumnavigating oceanic vessel, world-crisscrossing aircraft, or orbiting spaceship. This deck plan or blueprint of Spaceship Earth, made into a giant boardgame, laid Earth out with no North, South, East, or West and encouraged contemplation of the globe as a comprehensive whole. In 1974 Fuller's collaborator, student and cofounder of the World Game Institute (1972), Medard Gabel, published *Energy, Earth, and Everyone: A Global Strategy for Spaceship Earth*. Based on the World Game workshops and a program of "exhaustive inventorying" and in the context of geopolitical energy crises, Gabel's book "sought to demonstrate the technical feasibility of powering the entire world using only non-depletable energy sources."[61] The ambition was to make the planet comprehensible as a synergetic artifact, one that would supersede conceptions of Earth as simply a question of bounded territories. This transpired as a diverse and inclusive platform of energy fields, energetic relations, and calculable energy resources and expenditures and as a measure of vastly different kinds of cosmic capabilities.

Fuller's ambitions for a synoptic, unified worldview have informed the utopian narratives of the European Union's Roadmap 2050, and Shell's Scenarios and World Energy Model.[62] For Roadmap 2050, the Office for Metropolitan Architecture, working with the European Climate Foundation, visualized a utopia of connected cities—a continuous city named Eneropa—sharing energy from tidal, wind, solar, geothermal, and biomass resources. The Office for Metropolitan

Architecture's representation reveals interconnected, complementary energy strategies that exploit the geography and climate in different regions across the European continent. It replaces nations with new energetic entities—"Solaria," the "Isles of Wind," and "Geothermia." Although not daring to claim such connectivity could lead to world peace, it is clear that Eneropa's Europe-wide energy grid owes much to Fuller's World Game played on the Dymaxion map. And in the manner of Fuller, it redraws traditional conceptual and territorial boundaries in imagining a different kind of energy future for Europe.

Fuller's proposals for energy system change anticipated many contemporary discussions concerning energy. In the broader context of planetary-scale environmental disruptions caused by an escalating demand for energy, there are still calls for a far-reaching transformation of energy-provision systems and the entire reconfiguration of the energy sector toward new technical or institutional arrangements predicated on low-carbon sources. Current, cumulative worldwide investment in fossil fuel extraction and processing, however, continues to outstrip investment in renewables. And when few resources are so unequally consumed across the world as energy, notions of "us humans" all steering the spaceship or being in the same boat or connected for world peace are readily dismissed as illusory. Spaceship Earth and its energy grid has mainly endured as a metaphor that underpins notions of technical management and planetary control. Fuller's vision lent itself to a particular encompassing view—a way of perceiving the world as fabricated by humans and thus leaving humanity in charge of optimizing relations between energy resources and energy needs. In other words, Earth's cosmic-energy narrative could be reduced to a tally of inputs and outputs. Humanity was cast in the role of astronaut-accountants.

Planetary Boundaries

> This balmy springtime for humanity is known as the Holocene. But we are now in a new era, the Anthropocene, defined by human domination of the key systems that maintain the conditions of the planet. We have grabbed the controls of spaceship Earth, but in our reckless desire to "boldly go," we may have forgotten the importance of maintaining its life-support systems.
>
> —Fred Pearce, "From Ocean to Ozone"[63]

Knowledge of dynamic earth systems and the interactions of the atmosphere, hydrosphere, biosphere, heliosphere, cryosphere, lithosphere—air, water, life, sun, ice, and rock—has greatly expanded since Fuller's day. Acknowledgment of the significant ways in which humans are changing earth systems has unsettled existing notions of boundaries and threshold conditions and warned of planetary crisis and tipping points.[64] The renewed sense of planetary crisis is expressed in the concerted uptake of the idea of the Anthropocene—the proposal that devastating human-induced changes to earth systems signal a new geological epoch—and its "collateral concept" of planetary boundaries.[65] This discourse has drawn on 1960s narratives of Spaceship Earth and, in particular, its accounting procedures for maintaining Earth's life-support systems. Moreover, the strategic vantage point from whence Spaceship Earth could be both monitored and piloted signals a kind of "'de-Earthed' imaginary, the product of a technoscientific culture that developed in parallel with the dynamics that have led us into the Anthropocene."[66]

The planetary boundaries hypothesis, first proposed in 2009 by Johan Rockström and colleagues at the Stockholm Resilience Centre and updated in 2015, has become an influential framework for discussing global environmental problems and solutions.[67] The concept of planetary boundaries identifies nine global biophysical limits to human development: climate change, ocean acidification, stratospheric ozone depletion, biogeochemical nitrogen and phosphorus cycle levels, global freshwater use, land system change, biodiversity loss, chemical pollution, and atmospheric aerosol loading. It further suggests that transgressing any of these interdependent boundaries will have catastrophic consequences. With its emphasis on a "safe operating space for humanity" and its concerns over the "carrying capacity" of Earth, planetary boundaries thinking draws on the Spaceship Earth metaphor and on Fuller's terminology in *Operating Manual for Spaceship Earth*. It follows a persistent line of thought that frames environmental crises as a management problem within the notion of a limited and fragile planet. Earth is imagined as an operable biosphere, which inevitably conjures thought of Biosphere 2's grounded spaceship. The planetary boundaries hypothesis has also renewed discussions on appropriate stewardship of earth systems, understood as life-support systems *as if* on a spaceship. Mike Hulme warns that such powerful metaphors, circulating around

Earth, are never innocent. As he asks in his response to planetary boundaries thinking, "Is the Earth a spaceship to be steered on a journey, an Earth mother with which we must bond or, careful here, a dashboard with dials to be managed so that the indicators are kept out of the red zone?"[68] In the early twenty-first century the question of limits has thus resurfaced along with bold definitions of what those limits might be. These limits are accompanied by the terminology of tipping points, critical thresholds, and boundaries of abrupt climate and ecosystem change, which in turn have reenergized warnings of "deleterious or potentially disastrous consequences for humans."[69] Although current discourse around the Anthropocene and planetary boundaries acknowledges a good deal more uncertainty about the future than the "managing Spaceship Earth" precedents from the 1960s and 1970s ever admitted to, it nevertheless reveals the same blurring between ideas of stewardship and operational procedures. It also shares the same admixture of hubris and humility, marveling at human power and floored by its vulnerability. On the one hand, Rockström et al.'s vision is to promote the idea of planetary stewardship, or joint governance at the planetary scale, through revised research and policy collaborations such as the Earth League and Future Earth.[70] Rockström's vision is to "launch an Apollo type endeavor—which starts now—of addressing exactly this integrated science for transition to global sustainability."[71] On the other hand, the concepts of planetary boundaries, the safe and just operating space, green competition, and the energetic society have been enlisted as scaffolding for advancing toward sustainable-development goals in a move that claims to go beyond "cockpit-ism."[72] These conceptual moves that come packaged with an application of the notion of Spaceship Earth are underrecognized as such. Just as the earth sciences move toward thinking in terms of more dynamic systems and a cosmic expanding universe, so, paradoxically, their pronouncements also help to cement conservative responses focused on control, where concomitant notions of circular, causal relations and cybernetic dynamization produce their own kinds of fixities.

Fixing Spaceship Earth

Perhaps of most concern is that thinking in terms of operable life-support systems and planetary boundaries places humans in the role of

earth fixers. *Geoengineering* is a term that describes the planetary-scale technologically driven interventions in and management of the Earth. Current geoengineering options fall into two main categories: solar radiation management and carbon dioxide removal. Solar radiation management schemes for reflecting sunlight back into space include, for example, releasing sulphate particles into the stratosphere to enhance Earth's albedo, or global dimming, by placing millions of tiny mirrors in near-Earth space orbit. Carbon dioxide removal schemes to remove carbon dioxide from the atmosphere include the dumping of pulverized limestone into the oceans to neutralize acidification and the burial of charred biomass to promote carbon sequestration. The fundamental premise of such schemes is Earth altering. For the most part, geoengineering proposals assume that Earth is an operable system with flows of energy that can be controlled and mastered by humans. As Bonneuil and Fressoz observe, "still more here than with nuclear tests or the imaginary of 'Spaceship Earth,' the entire Earth is now explicitly reified as object of experimentation and control."[73]

The contemplation of planetary-scale engineering is increasingly presented as a necessary evil, as an inevitable plan B response to the emerging dangers of anthropogenic impacts on earth systems. Many are convinced that the climate system has the potential for sudden and dangerous shifts, that carbon mitigation efforts are failing or moving too slowly to avert environmental disaster, and that therefore the earth and sky need to be "fixed" or controlled in the manner of a planetary thermostat perhaps or an air-conditioning unit. Clive Hamilton responds, "As if we know enough to install and begin to operate a 'global thermostat.' Truly this qualifies as monstrous hubris."[74] The disastrous conditions of the so-called Anthropocene epoch and the trespassing of planetary boundaries can already be said to have come about as a result of human planetary-scale manipulation, through extractive energy systems and fossil-fueled accelerations. Geoengineering can thus be understood, then, as both a trigger and an ultimate response to the Anthropocene. But as Duncan McLaren has noted, "discourses of the 'Anthropocene' give a misplaced confidence in the controllability of Earth systems."[75] A position that maintains that all earth systems are already irrevocably and irreversibly affected by human activities leaves little choice but to take control of or even attempt to further enhance those systems. In other words, geoengineering could simply

be considered as an ongoing project of earth systems management and a continuation of the inevitable, if risky, program for steering Spaceship Earth.

Energy Accounts

While Fuller's astronauts had journeyed for 2 million years without realizing they were on a spaceship, Peter Sloterdijk points out that "human being-in-the-world . . . turns out actually to be being-on-board on a cosmic vehicle prone to faults."[76] Writing in 2009, on the occasion of COP (Conference of the Parties) 15, Sloterdijk returns to Fuller's notion of Spaceship Earth, as the contemporary model for the planetary whole—a whole that binds humans and the Earth together in a complex symbiosis. In what comes across as a reworking of Fuller's self-identification as "Trim-Tab," Sloterdijk proposes anthropotechnics as a means of surviving a turbulent world—a transformation of the human condition through the recognition and cultivation of technologically driven interactions and alliances of networks, humans, and nonhumans. Such hopes for a hybrid planet are echoed in Donna Haraway and others' concerns to reconfigure, recompose, and recuperate biological, social, cultural, political, technological, and energetic dimensions of human and nonhuman life.[77] This calls for a renewed understanding of earthian-astronaut energy-intensive forms of life in their full complexity (both fragile and impactful) and a reimagining of being in the world with energy. Spaceship Earth is also a story of earthly mobility and transformation.

Narratives around Spaceship Earth reveal many different stories or strategies for change. There are accounts that tend toward a hubristic expression of human potential, while other narratives present the limits of human agency. Another set of narratives ask the reader to follow the procedural rule book that seeks to control an errant humanity, yet others explore Earth as a hybrid energetic entity. Standing apart from and yet implicated in all of these is a body of unruly storytelling and provocative narrative improvisations. Fuller's energetic storytelling was a foundation for his "world accounting system based on energy" that recognized both a "synergetic universe" and a human history of "reckless and illogical energy expenditure." The challenges of energy system

change and the parallel and closely linked challenge of telling whole stories about energy have not changed much since Fuller's day. And while we puzzle over how to come to terms with a sense of jeopardy when it comes to energy transitions and climate change, we still tend to foreground those accounts we perceive as more certain and perhaps therefore (to some) more reassuring.

The Anthropocene story and its associated concept of planetary boundaries together warn of environmental threats and limits, and many commentators have understood this to encourage a focus on ideas of control, scientific authority, and incontrovertible evidence. For Melissa Leach such moves also imply "a closing down of uncertainty or at least its reduction into clear, manageable risks and consensual messages."[78] Some versions of planetary management extend ambitions far beyond the governance of merely human affairs (in all their intractable unruliness) and aspire to take even greater power over the earth system. Many fear that this logic puts society on a path that leads to large-scale geoengineering with unknown and unacknowledged consequences. Proponents seem unwilling to acknowledge that it was precisely the domineering rhetoric of control that got humanity into its current unstable relationship with its earthly home in the first place. This suggests that a significantly different kind of earth accountability is needed, informed by notions of care, solidarity, justice, and responsibility from within the diversity of human relations with energy.

However, whichever route is taken, the fact remains that despite the intensity and persistence of the challenges of steering a foundering Spaceship Earth, humans clearly don't have, and will never have, a reliable operating manual. What kind of energy narratives are possible in the so-called Anthropocene? Thinking about living with energy in this time of shipwreck and uncertainty suggests the need to go well beyond reliance on the capabilities of integrated knowledge systems or the processes of earth system governance. It also requires cultivating more plural accounts of human imagination and possibility rather than depending on fixed accounting procedures. Spaceship Earth narratives surface the contradictions of our contemporary relationships with energy and are a reminder that energy systems are likely to continue to be diverse, complicated, uneven, and contested, as well as changeable. While Fuller's storytelling has informed notions of a home planet as a

controllable artifact, it also points to a reentangling of diverse human values and aspirations with the unknowable and uncontrollable complexities of the earth and the "invisible energy events of the universe."[79] In the epilogue to *Utopia or Oblivion*, Fuller writes, "The environment always consists of energy—energy as matter, energy as radiation, energy as gravity, and energy as 'events.'"[80]

Fuller's energy accounts—from inventories, through mappings and games, to storytelling—were about imagining transformation and proposing a radically different energy future. At times, however, his unbounded faith in *human* energy and ingenuity and the promise of technological control seems misplaced, even dangerous. Many are cautious of Fuller's writings, on account of its thick vein of techno-optimism. Moreover, his exhilaration at Earth's cosmic bounty is at odds with the prevailing mood of doom that pervaded his own time and persists today, not least with escalating warnings of catastrophic environmental change. And yet his tales of human, or earthian, synergy with the home planet also convey a sense of wonder. The distinctive mix of audacity and urgency in R. Buckminster Fuller's energy accounts is timely. They suggest that there is potential not only in comprehending, calculating, and tallying our energy intensities and capacities but also in allowing for the uncurbed imagining of alternatives. This again feels like an important combination as humanity seeks dynamic stories that might help with the reimagination of energy transitions in the Anthropocene.

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NOTES

1. Stewart Brand writes, "Back in 1967 the insights of Buckminster Fuller initiated the *Whole Earth Catalog*. The artists I hung out with in those days had all been electrified by

Fuller's earlier, most radical book—*Nine Chains to the Moon*." Stewart Brand, ed., *The Next Whole Earth Catalog: Access to Tools*, 2nd ed. (New York: Random House, 1981), 32.

2. John Cage, "Diary: How to Improve the World (You Will Only Make Matters Worse)," *New Literary History* 3, no. 1 (1971): 201–14.

3. R. Buckminster Fuller, *Operating Manual for Spaceship Earth* (Baden, Switzerland: Lars Müller, 2008), 22–23.

4. Fuller's "comprehensive anticipatory design science" was originally outlined in 1927 while he was teaching at MIT.

5. R. Buckminster Fuller, *Your Private Sky: R. Buckminster Fuller; Discourse*, ed. Joachim Krausse and Claude Lichtenstein (Baden, Switzerland: Lars Müller, 2001), 18.

6. See Fuller, *Operating Manual*, 11.

7. R. Buckminster Fuller, *Utopia or Oblivion: The Prospects for Humanity* (1969; repr., Baden, Switzerland: Lars Müller, 2008), 26.

8. R. Buckminster Fuller, foreword to Medard Gabel, *Energy, Earth, and Everyone: A Global Strategy for Spaceship Earth* (New York: Anchor Books, 1980), 8.

9. See for example, William McDonough and Michael Braungart, *Cradle to Cradle: Remaking the Way Things Work* (New York: North Point Press, 2002).

10. See Timothy W. Luke, "Ephemeralization as Environmentalism: Rereading R. Buckminster Fuller's *Operating Manual for Spaceship Earth*," *Organization and Environment* 23, no. 3 (2010): 354–62.

11. Fuller, *Operating Manual, 60*.

12. See Sabine Höhler, *Spaceship Earth in the Environmental Age, 1960–1990* (London: Pickering and Chatto, 2015).

13. The term *Anthropocene* was introduced in 2000 by the atmospheric chemist Paul J. Crutzen and the ecologist Eugene Stoermer to refer to the present as geologically distinct from the geological epoch of the Holocene because of the scale of human impacts on earth systems. See Paul J. Crutzen and Eugene Stoermer, "The Anthropocene," *International Geosphere-Biosphere Programme Newsletter* 41 (2000): 17–18; Paul J. Crutzen, "Geology of Mankind," *Nature* 415 (January 2002): 23.

14. Will Steffen et al., "The Anthropocene: From Global Change to Planetary Stewardship," *Ambio* 40, no. 7 (2011): 739–61.

15. See Simon Dalby, "Framing the Anthropocene: The Good, the Bad and the Ugly," *Anthropocene Review* 3, no. 1 (2016): 33–51.

16. Fuller, *Utopia or Oblivion*.

17. See Dipesh Chakrabarty, "The Climate History: Four Theses," *Critical Inquiry* 35, no. 2 (2009): 197–222.

18. See Renata Tyszczuk, "Anthropocene Unconformities: On the Aporias of Geological Space and Time," *Space and Culture* 19, no. 4 (2016), 435–47.

19. See Imre Szeman, "Literature and Energy Futures," in "Editor's Column: Literature in the Ages of Wood, Tallow, Coal, Whale Oil, Gasoline, Atomic Power and Other Energy Sources," *PMLA* 126, no. 2 (2011): 324; and Szeman and Dominic Boyer, eds., *Energy Humanities: An Anthology* (Baltimore, MD: Johns Hopkins University Press, 2017).

20. Renata Tyszczuk, *Provisional Cities: Cautionary Tales for the Anthropocene* (London: Routledge, 2018), ix.

21. Denis Cosgrove, *Apollo's Eye: A Cartographic Genealogy of the Earth in the Western Imagination* (Baltimore, MD: Johns Hopkins University Press, 2001), 265, 289.

22. Cosgrove, *Apollo's Eye*, 2.

23. Kathryn Yusoff, "Excess, Catastrophe, and Climate Change," *Environment and Planning D: Society and Space* 27 (2009): 1017.

24. R. Buckminster Fuller, *Nine Chains to the Moon* (1938; repr., Carbondale: Southern Illinois University Press, 1963), 59.

25. Peter Sloterdijk, *Versprechen auf Deutsch: Rede über das eigene Land* (Frankfurt: Suhrkamp, 1990) 57; cf. Wolfgang Sachs, *Planet Dialectics: Explorations in Environment and Development* (London: Zed Books, 1999), 110.

26. Manfred E. Clynes and Nathan S. Kline, "Cyborgs and Space," *Astronautics*, September 1960.

27. Allison Muri, *The Enlightenment Cyborg: A History of Communications and Control in the Human Machine, 1660–1830* (Toronto: University of Toronto Press, 2006), 30.

28. See Donna J. Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," in *Simians, Cyborgs, and Women: The Reinvention of Nature* (London: Free Association Books, 1991), 149–81.

29. R. Buckminster Fuller, *Your Private Sky: R. Buckminster Fuller; The Art of Design Science*, ed. Joachim Krausse and Claude Lichtenstein (Baden, Switzerland: Lars Müller, 1999), 11.

30. Norbert Wiener, *The Human Use of Human Beings: Cybernetics and Society* (1950; repr., London: Free Association Books, 1989), 40.

31. Fuller, *Operating Manual*.

32. The concept of "carrying capacity" used by ecologists to define the maximum number of representatives of a given species that a habitat can support without permanently corrupting the environment and endangering the life of the species. It is closely linked to the notion of sustainable development and the discourse around ecological limits.

33. Fuller, *Operating Manual*, 60.

34. Fuller, *Operating Manual*, 59–60.

35. Fuller, *Operating Manual*, 128.

36. Fuller, *Operating Manual*, 128.

37. Fuller, *Operating Manual*, 129.

38. Fuller, *Utopia or Oblivion*, 301.

39. Fuller, *Operating Manual*, 129.

40. Fuller, *Operating Manual*, 138.

41. See Peder Anker, "The Ecological Colonization of Space," *Environmental History* 10, no. 2 (April 2005): 239–68; Peder Anker, "The Ecological Colonization of Space," in *From Bauhaus to Ecohouse: A History of Ecological Design* (Baton Rouge: Louisiana State University Press, 2010).

42. Kenneth E. Boulding, "The Economics of the Coming Spaceship Earth," in *Environmental Quality in a Growing Economy: Essays from the Sixth RFF Forum on Environmental Quality Held in Washington DC, March 8 and 9, 1966*, ed. Henry Jarrett (Baltimore, MD: Johns Hopkins University Press, 1966), 9.

43. Barbara Ward, *Spaceship Earth* (New York: Columbia University Press, 1966), 15.

44. Höhler, *Spaceship Earth in the Environmental Age*, 104.

45. Ward, *Spaceship Earth*, vii.

46. Ward, *Spaceship Earth*.

47. See Sabine Höhler, "'The Real Problem of a Spaceship Is Its People': Spaceship Earth as Ecological Science Fiction," in *Green Planets: Ecology and Science Fiction*, ed. Gerry Canavan and Kim Stanley Robinson (Middletown, CT: Wesleyan University Press, 2014), 99–114.

48. Oliver Morton, *The Planet Remade: How Geoengineering Could Change the World* (London: Granta, 2015), 77.

49. See James Lovelock, *The Vanishing Face of Gaia: A Final Warning* (London: Allen Lane, 2009).

50. Paul R. Ehrlich, *The Population Bomb* (New York: Ballantine, 1968).

51. Garrett Hardin, *Exploring New Ethics for Survival: The Voyage of the Spaceship Beagle* (New York: Viking Press, 1972), 233.

52. Hardin, *Exploring New Ethics*; Garrett Hardin, "The Tragedy of the Commons," *Science* 162 (1968): 1243–48. The original essay was included in the later book version as appendix B, 250–64.

53. Hardin, *Exploring New Ethics*, 92.

54. See Sabine Höhler, "The Environment as a Life Support System: The Case of Biosphere 2," *History and Technology* 26, no. 1 (2010): 39–58; Sabine Höhler, "'Spaceship Earth': Envisioning Human Habitats in the Environmental Age," *GHI Bulletin* 42 (2008): 65–85.

55. See Höhler, *Spaceship Earth in the Environmental Age*, 107.

56. Hugh Kenner, "Bucky Fuller and the Final Exam," *New York Times*, July 6, 1975, 151; see also Gabel, *Energy, Earth, and Everyone*, 1.

57. R. Buckminster Fuller, "Prime Design," in *Ideas and Integrities: A Spontaneous Autobiographical Disclosure* (1960; repr., Baden, Switzerland: Lars Müller, 2009), 328, originally published in *Bennington College Bulletin*, May 1960.

58. R. Buckminster Fuller, *Critical Path*, with Kiyoshi Kuromiya (New York: St. Martin's Press, 1981), xvii.

59. Fuller, *Critical Path*, xxxiv.

60. Fuller, *Critical Path*, 206.

61. Gabel, *Energy, Earth, and Everyone*, 6.

62. See "Roadmap 2050," European Climate Foundation, accessed April 20, 2018, http://www.roadmap2050.eu; "Shell Scenarios," Shell Global, accessed April 20, 2018, https://www.shell.com/energy-and-innovation/the-energy-future/scenarios.html.

63. Fred Pearce, "From Ocean to Ozone: Earth's Nine Life-Support Systems," *New Scientist*, February 24, 2010, https://www.newscientist.com/round-up/ocean-to-ozone-earths-nine-life-support-systems/.

64. Tim O'Riordan and Tim Lenton, eds., *Addressing Tipping Points for a Precarious Future* (Oxford: Oxford University Press / British Academy, 2013).

65. Noel Castree, "The Anthropocene and Planetary Boundaries," in *International Encyclopedia of Geography: People, the Earth, Environment, and Technology*, ed. Douglas Richardson, Noel Castree, Michael F. Goodchild, Audrey Kobayashi, Weidong Liu, and Richard A.

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66. Christophe Bonneuil and Jean-Baptiste Fressoz, *The Shock of the Anthropocene*, trans. David Fernbach (London: Verso, 2016), 63.

67. Johan Rockström et al., "A Safe Operating Space for Humanity," *Nature* 461 (2009): 472–75; Will Steffen et al., "Planetary Boundaries: Guiding Human Development on a Changing Planet," *Science* 347, no. 6223 (2015), https://doi.org/10.1126/science.1259855.

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69. Rockström et al., "A Safe Operating Space for Humanity."

70. Haraway, "How Is Pollution Dangerous for the Future of the Earth?," *Future Earth* (blog), October 15, 2018, http://www.futureearth.info/news/future-earth-launches-eight-initiatives-accelerate-global-sustainable-development.

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73. Bonneuil and Fressoz, *Shock of the Anthropocene*, 91.

74. Clive Hamilton, *Earth Masters: The Dawn of the Age of Climate Engineering* (New Haven, CT: Yale University Press, 2013), 181.

75. Duncan McLaren, "Where's the Justice in Geoengineering?," *Guardian*, March 14, 2015, http://www.theguardian.com/science/political-science/2015/mar/14/wheres-the-justice-in-geoengineering.

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77. See Donna Haraway, "Anthropocene, Capitalocene, Plantationocene, Chthulucene: Making Kin," *Environmental Humanities* 6 (2015): 159–65; see also Donna Haraway, introduction to Szeman and Boyer, *Energy Humanities*, 8–10.

78. Melissa Leach, "Democracy in the Anthropocene? Science and Sustainable Development Goals at the UN," *Huffington Post*, March 28, 2013, http://www.huffingtonpost.co.uk/Melissa-Leach/democracy-in-the-anthropocene_b_2966341.html.

79. Fuller, *Utopia or Oblivion*, 26.

80. Fuller, *Utopia or Oblivion*, 439.